aa501 graphicx

document Density profiles in a spherical infall model with non–radial motions

N. Hiotelis Present address: Roikou 17-19, Neos Kosmos, Athens, 11743 Greece N. Hiotelis

Lyceum of Naxos, Chora of Naxos, Naxos 84300, Greece

Received 3 September 2001 / Accepted 5 November 2001 A generalized version of the Spherical Infall Model (SIM) is used to study the effect of angular momentum on the final density profile of a spherical structure. The numerical method presented is able to handle a variety of initial density profiles (scale or not scale free) and no assumption of self-similar evolution is required. The realistic initial overdensity profiles used are derived by a CDM power spectrum. We show that the amount of angular momentum and the initial overdensity profile affect the slope of the final density profile at the inner regions. Thus, a larger amount of angular momentum or shallower initial overdensity profiles lead to shallower final density profiles at the inner regions. On the other hand, the slope at the outer regions is not affected by the amount of angular momentum and has an almost constant value equal to that predicted in the radial collapse case. galaxies: formation – halos – structure, methods: numerical

Introduction

It is likely that dark matter halos are formed by the evolution of small density perturbations in the early Universe. The matter contained in a perturbed region progressively detaches from the general flow and after reaching a radius of maximum expansion it collapses to form an individual structure. The most simple case is when this region is spherical, isolated and undergoing a radial collapse. This is the spherical infall model (hereafter SIM). SIM has been extensively discussed in the literature (Gunn & Gott gunn72; Gott gott; Gunn gunn77; Fillmore & Goldreich fillmore; Bertschinger bert; Hoffman & Shaham hoffman, hereafter HS; White & Zaritsky white).

The final density profile after a collisionless evolution of the matter depends on its initial density profile and the underlying cosmology. Self-similarity solutions (Fillmore & Goldreich fillmore; Bertschinger bert, HS) show that a power-law initial density profile relaxes to a final density profile given by $\rho(r) \propto r^{-\alpha}$ with $\alpha \geq 2$. Furthermore, recent numerical studies that relax the assumption of self-similarity, also give final density profiles steeper than r^{-2}. Lokas & Hoffman (lokas01) found values of α in the range 2 to 2.3.

The density profiles of galactic halos do not seem to follow power laws. Numerical studies (Quinn et al. quinn; Frenk et al. frenk; Dubinski & Galberg dubinski; Crone et al. crone; Navarro et al. navarro; Cole & Lacey cole; Huss et al. huss; Fukushinge & Makino fuku; Moore et al. moore; Jing & Suto jing) showed that the profile of relaxed halos steepens monotonically with radius. The logarithmic slope $\alpha = -d\ln\rho d\ln r$ is less than 2 near the center and larger than 2 near the virial radius of the system. The value of α near the center of the halo is not yet known. Navarro et al. (navarro) claimed $\alpha = 1$ while Kravtsov et al. (kravtsov) initially claimed $\alpha \sim 0.7$ but in their revised conclusions (Klypin et al. klypin) they argue that the inner slope varies from 1 to 1.5. Moore et al. (moore) found a slope $\alpha = 1.5$ at the inner regions of their N-body systems.

The spherical infall model (SIM)

SIM is based on the physical process described in Gunn (gunn77) and in Zaroubi & Hoffman (zaroubi): In an expanding spherical region the maximum expansion radius ζ (apapsis) of a shell is a monotonic increasing function of its initial radius x_i and is given by the relation:

equation0 equation $\zeta = g(x_i) = 1 + \Delta_i(x_i)1 - \Omega_i^{-1} + \Delta_i(x_i)x_i, eqb1$

where Ω_i is the initial value of the density parameter of the Universe and Δ_i is the relative excess of mass inside the sphere of radius x_i, given by

equation $\Delta_i(x_i) = M(x_i) - M_b(x_i)M_b(x_i) = 3x_i^3\int_0^{x_i} x^2\delta_i(x)dx.eqb2$

In (eqb2), M is the mass of the spherical region, M_b is the mass of the unperturbed Universe and δ_i is the spherically symmetric perturbation of the density field ($\delta_i(x) = \rho(x) - \rho_{b,i}\rho_{b,i}$ where ρ is the density and $\rho_{b,i}$ is the constant density of the homogeneous Universe at the initial conditions). The time spent for a shell to reach its above turnaround radius is: equation $\mathrm{t}_{ta} = 1 + \Delta_i(x_i)2H_i\Omega_i^{1/2}[1 - \Omega_i^{-1} + \Delta_i(x_i)]^{32}\pi, eqb3$

equation $\rho_{ta}(\zeta) = (x_i\zeta)^2\,\rho_i(x_i)\,(d\zeta dx_i)^{-1}\,.eqb4$

In deriving (eqb4) the conservation of mass is used ($M(x_i) = M(\zeta)$). This is an important relation since this distribution of mass is used as the initial one in SIM. SIM assumes that the collapse is gentle enough. This means that the orbital period of the inner shell is much smaller than the collapse time of the outer shells (Zaroubi & Hoffman zaroubi). This implies that the radial action $\oint v(r)dr$, where v is the radial velocity, is an adiabatic invariant of the inner shell. As the outer shells collapse, the potential changes slowly and because of the above adiabatic invariant, the inner shell shrinks. The collapse factor depends on the time the mass of the outer shells (passing momentarily) spends inside the inner shell. Consider a shell with apapsis ζ and initial radius x_i. The mass inside radius ζ is a sum of two components. The first one, (permanent component, M_p), is due to the shells with apapsis smaller than ζ and the second (additional mass, M_{add}) is the contribution of the outer shells passing momentarily through the shell ζ. Because of the mass conservation, the permanent component is given by the following relation equation $\mathrm{M}_p(\zeta) = M(x_i) = 43\pi\rho_{b,i}x_i^3[1+\Delta_i(x_i)].eqb5$

equation $\mathrm{I(r)}{=}\int_{x_p}^{r} dnv_x(n),$